

The SEMATECH Berkeley MET: extending EUV learning to 16-nm half pitch

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ABSTRACT

Several high-performing resists identified in the past two years have been exposed at the 0.3-numerical-aperture (NA) SEMATECH Berkeley Microfield Exposure Tool (BMET) with an engineered dipole illumination optimized for 18-nm half pitch. Five chemically amplified platforms were found to support 20-nm dense patterning at a film thickness of approximately 45 nm. At 19-nm half pitch, however, scattered bridging kept all of these resists from cleanly resolving larger areas of dense features. At 18-nm half pitch, none of the resists were able to cleanly resolve a single line within a bulk pattern. With this same illumination a directly imageable metal oxide hardmask showed excellent performance from 22-nm half pitch to 17-nm half pitch, and good performance at 16-nm half pitch, closely following the predicted aerial image contrast. This indicates that observed limitations of the chemically amplified resists are indeed coming from the resist and not from a shortcoming of the exposure tool. The imageable hardmask was also exposed using a Pseudo Phase-Shift-Mask technique and achieved clean printing of 15-nm half pitch lines and modulation all the way down to the theoretical 12.5-nm resolution limit of the 0.3-NA SEMATECH BMET.

Keywords: EUV, MET, Resist, Lithography, Berkeley, Phase-Shift-Mask, Frequency Doubling, SEMATECH, 22 nm, 16 nm

1. INTRODUCTION

Microfield exposure tools¹⁻³ have and continue to play a dominant role in the development of extreme ultraviolet (EUV) resists and masks. One of these tools is the 0.3-numerical-aperture (NA) SEMATECH Berkeley Microfield Exposure Tool (BMET).¹ With its unique engineered coherence capabilities⁴ the BMET is able to access aerial image resolutions well beyond the 22-nm limit of the current champion chemically amplified (CA) resist.⁵ Recently, several high-performing CA resists identified in the past two years were exposed at the BMET using an illumination optimized for 18-nm half pitch, in order to benchmark their ultimate performance. In addition, a directly imageable metal oxide hardmask was exposed at the BMET using a pseudo phase-shift-mask technique to test the resolution capabilities of both the tool and the imageable hardmask formulation. This paper describes these experiments and summarizes their results.

2. EUV PRINTING RESULTS

Using engineered illumination, the BMET can access high-contrast aerial images for almost any pitch supported by the NA of the optic. With an NA of 0.3, the theoretical minimum supported half pitch is approximately 12-nm. Recently, an illumination was developed that is optimized for 18-nm half pitch. It is shown in Figure 1 (left). The poles are separated by the NA created by an 18-nm half pitch feature and offset vertically by the width of the central stop to avoid pitch deadbands. When illuminating 18-nm half pitch vertical lines, the ± 1 orders created by one pole perfectly overlap the other pole, producing a symmetric interaction with the pupil, minimizing aberrations and creating a high-fidelity aerial image. Figure 1 (right) shows the computed aerial

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image contrast for this illumination setting from 12-nm half pitch to 22-nm half pitch. The dramatic contrast roll-off between 17-nm half pitch and 14-nm half pitch is due to apodization of + 1 order by the outside of the pupil.

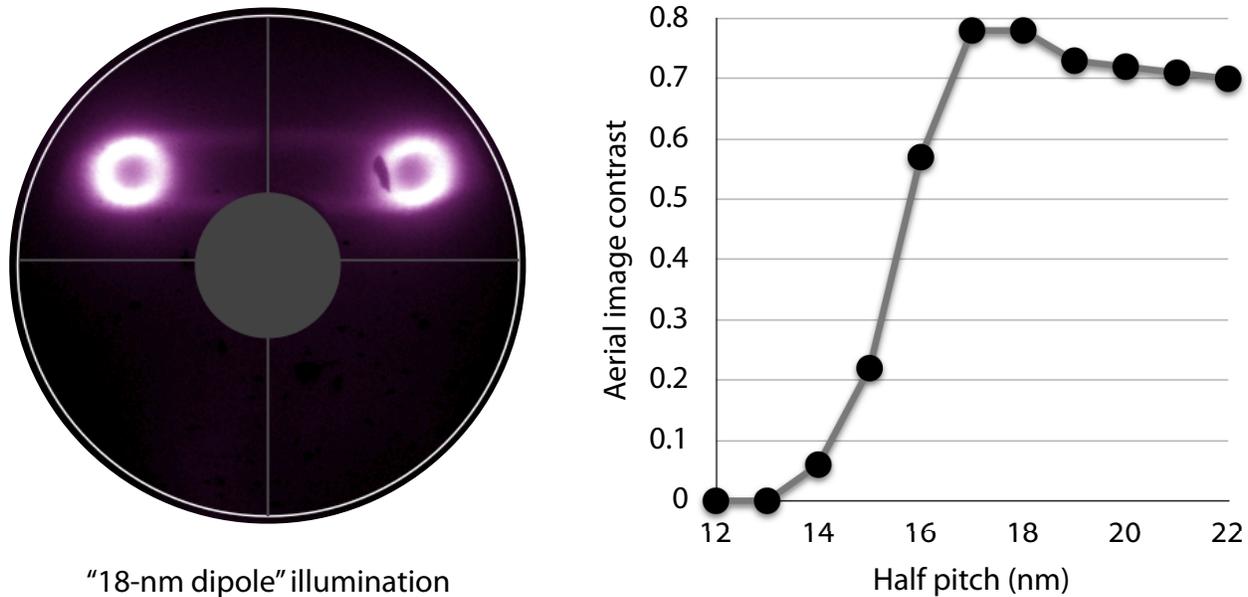


Figure 1. Engineered pupil fill optimized for 18-nm half pitch. The poles are separated by the NA created by an 18-nm half pitch feature and offset vertically by the width of the central stop to avoid pitch deadbands.

2.1 Demonstration of aerial image delivery

The only way to prove the tool is in fact capable of delivering the aerial image contrast shown in Figure 1 is to demonstrate printing throughout the contrast band. Figure 2 shows through-pitch dense printing in a directly imageable metal oxide hardmask provided by Inpria Corporation (XE15AB), using the illumination optimized for 18 nm. Excellent performance is achieved at all pitches with an aerial image contrast above 70% (22-nm half pitch to 17-nm half pitch), and good performance is achieved at 16-nm half pitch with an aerial image contrast of approximately 60%, indicating the tool is operating as expected.

2.2 Benchmarking several of 2010’s high-resolution candidates

Having demonstrated good 22-nm half pitch performance with single patterning at EUV in chemically amplified resists in 2008,⁵ the goal has been pushed to 20-nm half pitch and below. To benchmark the ultimate performance of current chemically amplified platforms at EUV, several of the high-performing resists identified in the past two years have been exposed with the 18-nm dipole illumination setting discussed in the previous section. Figure 3 shows printing results in all of the resists that were screened: five chemically amplified resists and the directly imageable metal oxide hardmask. All resists are on HMDS-Si, less the metal oxide hardmask, which is on bare Si. FT in Figure 3 corresponds to film thickness in nm.

All of the materials that were screened support 20-nm half pitch dense patterning at a film thickness less than 45 nm. Some of the chemically amplified resists are close to supporting 19-nm half pitch, but scattered bridging is keeping them from cleanly resolving a bulk area of 19-nm dense features. At 18-nm, none of the chemically amplified resists are able to cleanly resolve a single line within a bulk pattern; however, the directly imageable hardmask shows excellent performance and continues to perform down to 16-nm with this illumination setting. Although the data is not shown here, a subset of the chemically amplified resists were also tested at 60-nm film thickness, and each one suffered from pattern collapse issues at the 20-nm half pitch target.

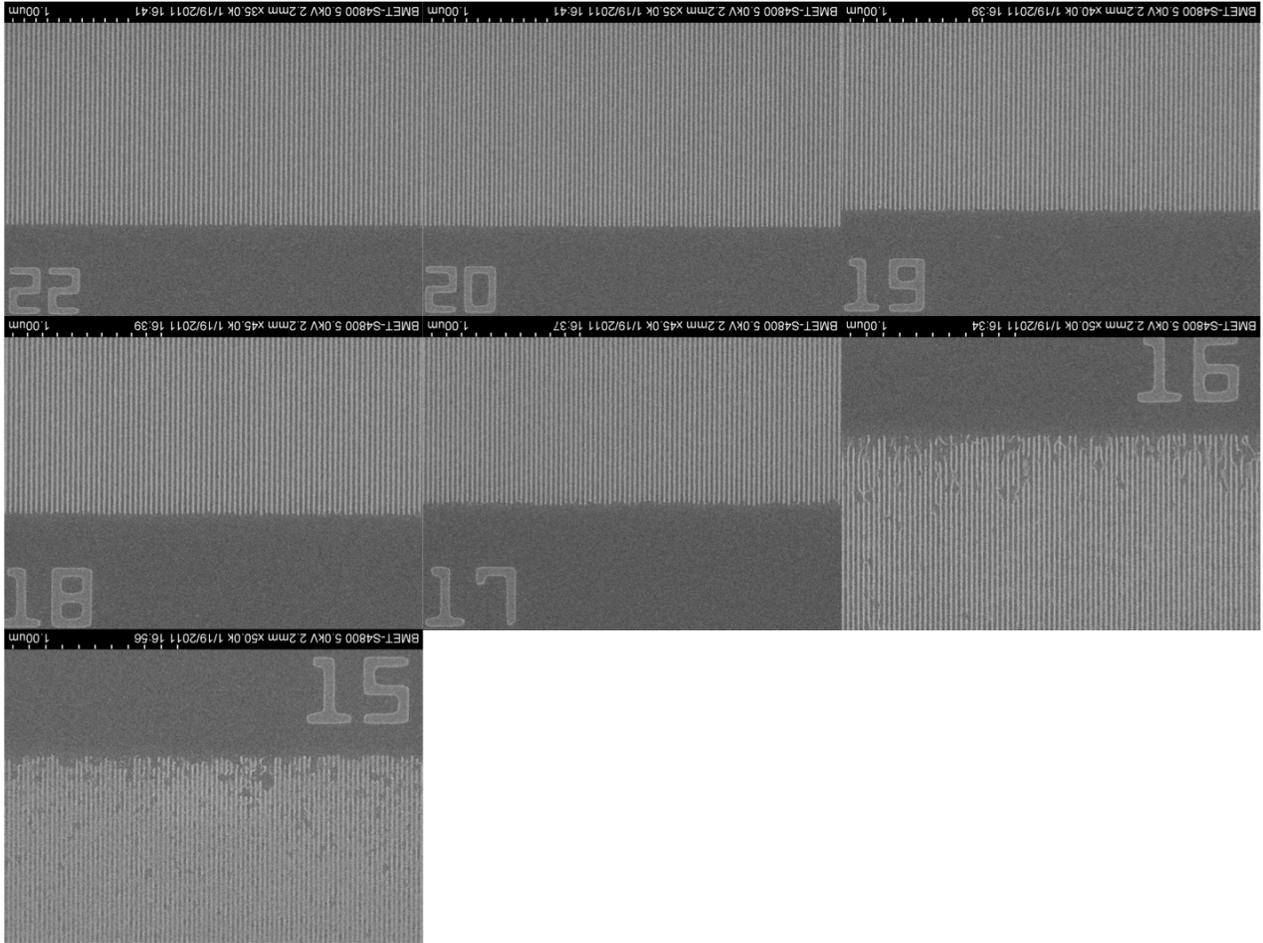


Figure 2. Through-pitch dense printing in a directly imageable metal oxide hardmask provided by Inpria Corporation, using an engineered illumination optimized for 18-nm half pitch. The large number in each figure is the half pitch of the feature that is shown.

2.3 Pseudo Phase Shift Mask patterning (frequency doubling)

A chromeless phase shift mask enables pitch splitting by suppression of the zeroth diffracted order from the line-space pattern on the mask. This is achieved by having a perfect π phase shift between the line and the space while simultaneously having constant reflectivity from both the line and space. In such a case, the average field value (DC term) at the exit surface of the phase shift structure is zero and thus the zeroth diffracted order is suppressed.

This same effect can be achieved with a conventional mask through spatial filtering at the Fourier plane of the mask pattern. The technique, however, requires a pupil fill that is small relative to the separation of the diffraction orders so the zeroth order can be selectively blocked. The BMET is ideal for this technique because it supports σ values below 0.1 and has a central obscuration built in that can serve as the zero order block. We refer to this process as Pseudo Phase Shift Mask (Pseudo-PSM) because it provides a functional equivalent to the chromeless phase shift mask while using a conventional binary amplitude mask. Figure 4 shows a schematic of this process along with exposures of 45-nm lines and spaces using both conventional illumination and the Pseudo-PSM method which results in twice as many 22.5-nm lines and spaces.

In 2010, the Pseudo-PSM technique was used to demonstrate modulation down to 15-nm half pitch in a non-optimized formulation of the imageable hardmask previously discussed.⁶ Improvements to the BMET illuminator have since improved the suppression of the zero order for Pseudo-PSM applications. In addition, the imageable

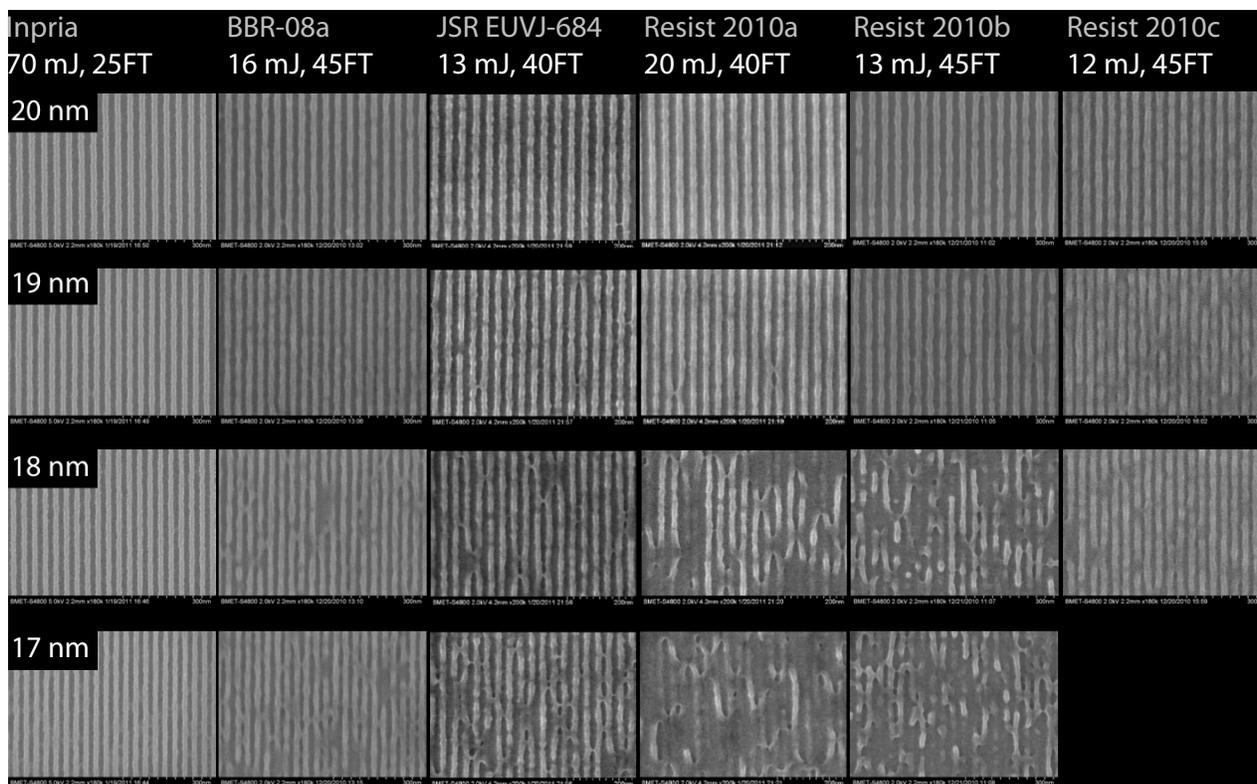


Figure 3. Through-pitch dense printing in five chemically amplified resists and a directly imageable metal oxide hardmask using an engineered illumination optimized for 18-nm half pitch. All resists are on HMDS-Si, less the metal oxide hardmask, which is on bare Si. FT = film thickness in nm.

hardmask formulation from Inpria Corporation has been refined for improved resolution at EUV. Figure 5 shows the latest Pseudo-PSM printing results from a formulation of the imageable hardmask optimized for ultimate resolution, demonstrating clean printing at 15 nm and modulation all the way down the the theoretical resolution limit of the exposure tool.

3. SUMMARY

Several high-performing resists identified in the past two years were found to support 20-nm dense patterning at a film thickness of approximately 45 nm. Below 20-nm half pitch, bridging and LER effects kept all of these resists from cleanly resolving larger areas of dense features. With the same imaging conditions a directly imageable metal oxide hardmask achieved excellent printing from 22-nm half pitch to 17-nm half pitch, and good printing at 16 nm, indicating that observed limitations of the chemically amplified resist are indeed coming from the resist and not from a shortcoming of the tool. Using a Pseudo Phase-Shift-Mask imaging technique the same imageable hardmask achieved clean printing at 15-nm half pitch and modulation all the way down the the theoretical resolution limit of the exposure tool.

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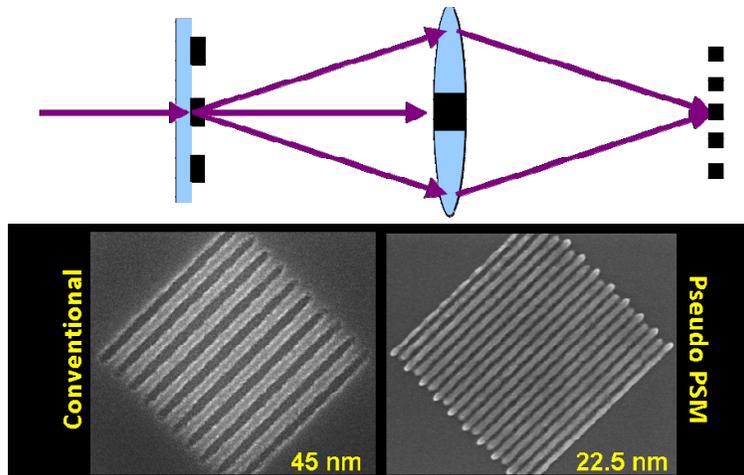


Figure 4. Schematic of the pseudo-PSM process along with exposures of 45-nm lines and spaces using both conventional illumination and the Pseudo-PSM method which results in twice as many 22.5-nm lines and spaces.

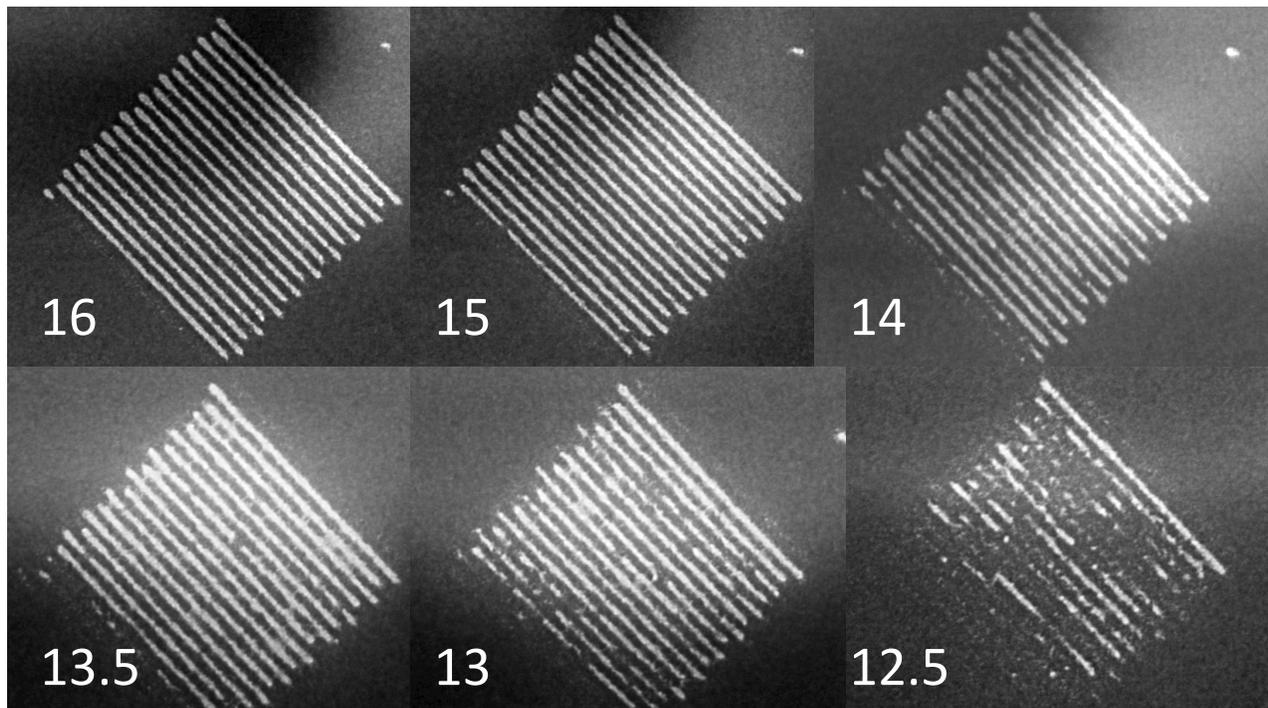


Figure 5. Pseudo-PSM mode printing in a directly imageable metal oxide hardmask provided by Inpria Corporation.

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